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Preparing Teachers to Make the Formative Assessment Process Integral to Science Teaching and Learning

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Abstract Formative assessment provides a means to successfully scaffold learning. Unfortunately, few teachers understand the pedagogical implications of such scaffolding or their role in utilizing formative assessments. The purpose of our study was to develop an understanding of the experience of being a teacher that is seeking to improve learning through formative assessment and using that understanding to improve our practices in teacher education. Three categories emerged from the data analysis: (1) questioning the validity of tacit pedagogical understandings, (2) understanding the experiences of the students, and (3) exploring the need to develop a more reflexive classroom. The findings from this study are useful for persons seeking to prepare teachers to guide science learning.

Keywords Formative assessment · In-service teacher education · Action research

Introduction

The National Research Council (NRC 1999, 2007) and the American Association for the Advancement of Science (AAAS 1998), as well as educational researchers (e.g., Black and Wiliam 1998; Shepard 2000, 2005) have appealed for a broader, more inclusive range of classroom assessment that reflects the complexity and interconnectedness of science as a discipline. Assessments and the interpretations of their outcomes have direct and lasting impacts on teachers, learners, and classroom activities. Assessments should serve to enrich students' understanding of science and not simply measure attainment of content knowledge. To this end, formative assessment should be an essential feature of classroom practice since the

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development and implementation of formative assessment serves to support science standards and promote learning (Atkin et al. 2001).

In order to support inservice teachers in the enactment and refinement of formative assessment practices in science classrooms, as teacher educators, we must develop our own understanding of teachers' experiences with implementing formative assessment and the challenges and benefits of doing so. Our study investigated the experiences of a middle school science teacher who implemented formative assessment in her classroom while engaging in cooperative inquiry with postsecondary researchers. This study contributes to the research on formative assessment in science classrooms by informing readers of the practical implications of implementing formative assessment through cooperative inquiry, and then subsequently utilizing those inquiry outcomes to direct teaching and learning.

Theoretical Framework

There are several key characteristics that define classroom assessment practices as formative. First, we consider formative assessment as any planned or spontaneous pedagogical strategy used to elicit students' conceptual development during instruction. This differs from summative assessment, which elicits students' knowledge and skills for the primary purposes of documenting achievement and awarding grades. Formative assessment is embedded in teaching, tied to instructional goals, and carried out seamlessly as part of instructional activities (Abell and Volkmann 2006). Second, formative assessment has a contextual nature; it is influenced by learning situations, specific instructional activities, the teacher's knowledge of students, and the purpose of the lesson (Bell and Cowie 2001; Black and Wiliam 1998). Third, formative assessment is an ongoing, dynamic, and progressive process that relies on both verbal and nonverbal information from students as sources of evidence of learning. Our conceptualization of the formative assessment process is illustrated in Fig. 1.

Effective formative assessments are dependent on the teacher's ability "to interpret observations and student outcomes, and consequently act upon the interpretations to enhance student learning" (Jones and Moreland 2005, p. 196). Teachers must be adept at eliciting and recognizing ideas articulated by students, and use students' responses as resources to direct subsequent instructional decision-making in a way that supports learning (Otero and Nathan 2008; Ruiz-Primo and Furtak 2007).

When used properly, formative assessment gives students feedback about their learning and provides them with an opportunity to take charge of their educational progress, thereby enhancing their autonomy and self-regulation (Latta et al. 2007). Feedback given by teachers should be iterative in that it affords students with opportunities to demonstrate learning from feedback (Black and Wiliam 1998). In order for feedback to be effective, students must understand learning goals, be able to compare their current level of performance with the learning goals, and take action to progress towards those goals (Sadler 1989). Thus, students need to be

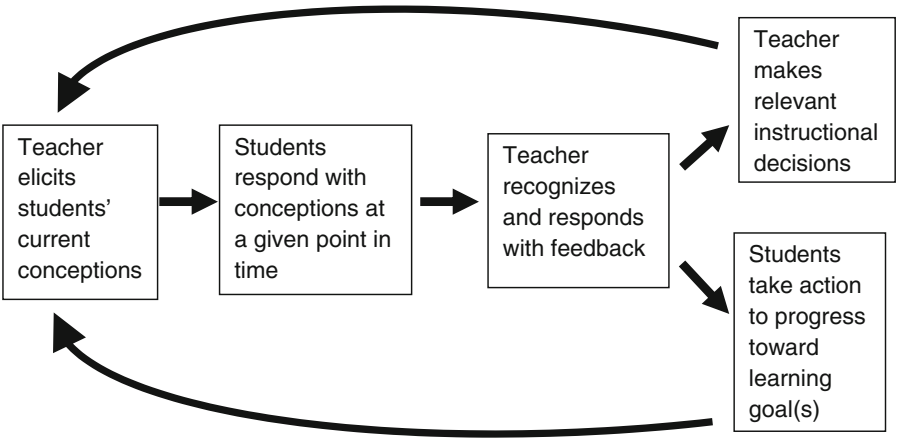

Fig. 1 An iterative model of classroom formative assessment adapted from Sadler (1989), Otero and Nathan (2008)

active participants in learning by assessing their efforts in light of objectives and sharing responsibility for taking actions to promote learning (Atkin et al. 2001).

Inservice Teachers' Formative Assessment Practices

Both formative and summative assessments influence learning, but their implementation in classrooms depends on teachers (Black and Wiliam 1998). Many teachers overemphasize summative assessment and consider formative assessment an unnecessary addition to their workload (NRC 1999). In order to transform classroom assessment practices, it is necessary to shift teachers' conceptions of assessment away from dominating notions of accountability and achievement to more holistic purposes of gathering evidence useful for informing teaching and learning practices (Shepard 2000). This requires changes to teachers' conceptions and beliefs about the forms and purposes of assessment as well as changes to their pedagogy.

Teachers' reasoning in selecting formative assessment tasks is influenced by their perceptions of students' abilities and the curriculum (Tomanek et al. 2008). Morrison and Lederman (2003) found a discrepancy between teachers' stated beliefs about the importance of diagnosing students' conceptions and their actual classroom practices. In this study, four secondary science teachers expressed importance in diagnosing students' conceptions and using them to guide instruction. Yet, none of the teachers used formal means for eliciting students' conceptions; in fact, whole class questioning was the most common formative strategy, but most questions probed only low level recall knowledge. In addition, none of the teachers were observed addressing students' misconceptions elicited through questioning. McMillan (2003) interviewed secondary teachers about their assessment practices and found teachers' assessment decisions were highly individualized and idiosyncratic, rather than based on common assessment principles. Teachers' decisions

were also influenced by school context and professional experiences, rather than preservice academic experiences.

Teachers' conceptions of learning also have been shown to be mediating factors in assessment practices. A comparative study on teachers' assessment practices by Marshall and Drummond (2006) indicated that teachers who held traditional, fixed views of learning and students' abilities were more likely to perceive external constraints, such as standardized testing, inhibited their use of formative assessment. As a result, they were less likely to implement formative assessment strategies. Yung (2001a, b) examined conceptions and beliefs of teachers implementing classroom assessments imposed by a school-wide reform. For teachers who viewed assessment primarily as a means of educational accountability, assessment was regarded as an activity distinct from teaching. Teachers integrated the roles of assessment and instruction when they viewed assessment as a means for serving the best interests of students. Jones and Moreland (2005) found weak pedagogical content knowledge (PCK) to be another mediating factor in formative assessment. Teachers with weak PCK neither engaged readily with students in assessment conversations, nor provided sufficient relevant or detailed feedback to students about their learning.

In order for teachers to significantly change their pedagogy related to assessment they need to deliberately and explicitly reflect on their beliefs. (Atkin et al. 2001). Teachers more readily reevaluate learning goals, adjust their pedagogy, and provide specific guidance to students when they self-reflect on instructional practices (Ash and Levitt 2003). When they understand learners' thinking, teachers choose more effective strategies for helping learners move toward deeper conceptual understanding. Likewise, Gearhart et al. (2006) found when teachers enacted cycles of assessment implementation and reflection they were able to strengthen their interpretations of student work, improve the specificity of learning goals, and enhance the quality of assessment tasks. Reflecting on assessment conceptions and beliefs enables teachers to become more self-aware of how their interpretations and judgments influence assessment processes (McMillan 2003).

Enhancing Inservice Teachers' Formative Assessment Practices

Black and Wiliam (1998) recommended that teachers need tools and professional support if they are to implement high-quality assessments and use assessment outcomes effectively. The impact of professional development on teachers' formative assessment practice has been recently well-reported in science education research (e.g., Bell and Cowie 2001; Feldman and Capobianco 2008; Torrance and Pryor 2001; Wiliam et al. 2004).

In a study by Torrance and Pryor (2001), teachers undertook action research projects after participating in professional development in order to explore the efficacy of specific formative 'interventions' in their classrooms. After reflecting on their assessment practices, teachers were able to plan more explicit formative assessments and work collaboratively with students to refine learning goals and evaluative criteria. Wiliam et al. (2004) worked collaboratively with 24 secondary teachers to develop formative assessment strategies aligned with their classroom

practices. They suggested that participation in professional development helped teachers continuously improve the types and amount of formative assessment used in their classrooms. Feldman and Capobianco (2008) worked with high school physics teachers to improve their use of technology-embedded formative assessment. The teachers participated in professional development on technology, and then embedded formative assessment into their lessons. Although teachers' understanding of formative assessment increased as they developed expertise in utilizing technology, this technological expertise did not necessarily translate into expertise with creating and using formative assessments.

While professional development is valuable for educating teachers about formative assessment, it cannot be simply another strategy to add to teachers' pedagogical toolboxes. Instead, teacher education on formative assessment should focus on the processes necessary to transform teaching, learning, and relationships within the classroom. Introducing assessment innovation through professional development alone will not achieve policy objectives unless the differing, interlocked conceptions of teachers are exposed and addressed (Brown 2004).

To address traditional assessment practices and tacit conceptions about student learning, we took a cooperative and reflexive approach to transforming formative assessment practice in the science classroom. Studies have indicated the role of collaborative action research on formative assessment practice in classrooms (e.g., Feldman and Capobianco 2008; Sato 2003; Torrance and Pryor 2001), with fewer studies documenting changes in classroom assessment through reflective practice by teachers (e.g., Ash and Levitt 2003, Gearhart et al. 2006). As reflective decision-making is essential to effective teaching and instructional planning (McMillan 2003), a cooperative and reflexive approach was utilized herein.

Our work was cooperative in that we, as teacher educators, collaborated with a classroom teacher to explore the challenges and benefits of implementing formative assessment. Moreover, our work was reflexive in that we followed a reciprocally educative process in which reflection and action occurred simultaneously. Designing formative assessment was both guided and informed by data analysis. Conceptions of the teacher, the students, and teacher educators were continually revised and enhanced as we faced successes and challenges in the science classroom. Our research followed a process in which design, data, and theory were emergent, with data generated from individuals working cooperatively (Heron and Reason 2002; Lather 1987).

Purpose

The purpose of our study was to develop an understanding of a teacher's experiences with implementing formative assessment and the challenges and benefits of doing so. To capture the essence of these experiences, our research was guided by the following questions:

1. To what extent, if any, does the cooperative research process affect the teacher's understanding of the formative assessment process?

2. What student experiences emerged as a result of formative assessment? To what extent did students' experiences influence instructional practices?
3. What practical implications emerged as a result of integrating formative assessment into daily instructional practices?

Method

Selection of a methodology was influenced by our desire for a cooperative and reflexive approach that fostered deep understanding of relevant issues facing a classroom teacher (Anderson and Mitchener 1994; Greenwood and Levin 1998). Cooperative inquiry is a form of action research; the aim is to work with others who have similar interests in order to understand and improve work in a shared world. At the heart of this approach lies the notion that people are competent in formulating their own conceptions of a process and aligning those conceptions to their praxis. In cooperative inquiry, the distinction between subject and researcher blurs as all active subjects become co-researchers. This method lends itself to a reflexive approach as research and practice occur simultaneously and influence one another.

Context and Participants

This study was situated in a middle school located in a Midwestern U.S. school district with 30,688 students. The middle school had a total enrollment of 521 students with a minority population of 35.9%, which was greater than the overall minority population for the district (13.7%). Our efforts focused on two sections of a 6th-grade course in which life, physical, and chemical science were taught as discrete subjects during different portions of the academic year. The cooperative inquiry group included two teacher educators and a sixth-grade science teacher with more than 3 years of classroom experience. The teacher had participated in professional development on formative assessment and was seeking support to incorporate formative assessment into her established instructional plans and classroom practices.

In order to develop a comprehensive understanding of the formative assessment process, we included student voices. As educational researchers, we believe that understanding assessment must account for diversity within the classroom population (Harnish 1994; Lawrenz et al. 2001; Wiggins 1989). From this classroom a purposeful sample of students was drawn; the sample included one African American male, one Caucasian male, two Native American females, two Caucasian females, one Middle Eastern female, one African American female, and one Asian male. All names are pseudonyms to protect students' confidentiality.

Data Collection

We collected data by meeting regularly and collaborating with the teacher on her formative assessment practices. Data sources included transcripts from weekly

planning sessions, instructional lesson plans, teacher interviews, student interviews, classroom observations, and student work.

The teacher was interviewed prior to and at the conclusion of the study. Sample preproject interview questions included (a) what does formative assessment mean to you, (b) what impacts do you believe incorporating formative assessment will have on students, and (c) do you believe there will be any barriers that will prevent you from utilizing formative assessment? Sample postproject interview questions included (a) to what extent has your understanding of formative assessment has changed since the beginning of the year, (b) what impact did incorporating formative assessment have on the students, (c) to what extent did these impacts differ among the students, (d) where there barriers that prevented you from utilizing formative assessment, and (e) what aspects of this experience were most/least beneficial?

Nine weekly planning sessions were audiotaped and transcribed verbatim. These planning sessions, which occurred at the middle school, focused on reviewing formative assessment strategies from the current week and developing plans for the upcoming week. The planning sessions were also guided by actual classroom experiences and student interviews.

Each student was interviewed approximately seven times during the study. The students were asked questions related to formative assessment strategies being utilized. These questions clarified information elicited by formative assessments. Interview questions included—Your teacher gave me a copy of this worksheet. Can you tell me about it? And, can you explain the difference between a plain, plateau, and mountain? In several instances, content-related visuals were provided to aid students in their explanations.

Classroom observations occurred eight times during the study using a modified version of an instrument developed by the Systemic Teacher Excellence Preparation program at Montana State University (Online Evaluation Resource Library 2001). This protocol focused classroom observations on the classroom environment, student engagement, teacher and student comments and questions, formative assessment strategies, and evidence of student learning.

Written student documents included formative assessments, worksheets, homework, quizzes, and tests. All student documents were photocopied and became part of the data set.

Data Analysis

Data analysis was an iterative process that occurred concurrently with data collection, during group planning sessions, and at the completion of our study. Planning sessions with the teacher provided us with opportunities to evaluate the efficacy of current formative assessment strategies and identify approaches that would improve learning outcomes. We discussed emergent themes, similarities and differences among our interpretations, and future directions for practice. This continuous analysis became part of the transcripts from planning sessions, which in turn served as additional data for analysis at the completion of our study.

Data analysis followed two strategic methods, direct interpretation and categorical aggregation (Stake 1995), which was an inductive process of narrowing from the particular codes to larger themes (Creswell 2002) under each research question. Composition of each theme was structured for overall consistency and change over time. Peer debriefings were conducted throughout the study. During these sessions co-researchers critiqued the method and checked interpretations emerging from data (Creswell and Miller 2000). Individual perspectives of research team members, representing different theoretical perspectives, came together to identify themes and analyze data. Member checking also played an important role in validating data and interpretations (Creswell and Miller 2000). Findings in the final cumulative report were then reviewed for completeness and credibility (Guba 1978) by the research team.

Findings

The reciprocally educative nature of a cooperative inquiry does not lend itself easily to categorical descriptions of findings. As a result, we provide a narrative that allows for an overall understanding of our experiences.

To what extent, if any, does the cooperative research process affect the teacher's understanding of the formative assessment process? Initially, the teacher indicated that she frequently reviewed in-class assignments with the whole class as a means of understanding students' knowledge construction. Most often, these in-class assignments included selected response items, such as matching. Although the teacher was aware of formative assessment strategies such as writing prompts, journals, and written feedback, she did not believe many of these strategies were feasible in her teaching assignment. She perceived her students' writing skills to be limited, and as a result, she had never allowed students to freely respond in open-ended assignments or to prompts. Through dialogue with the teacher, we discovered that her tacit impressions of students' conceptual understandings were most often based on students' responses to in-class assignment reviews.

In order to determine the efficacy of selected response assessments in eliciting students' conceptions, the research team interviewed individual students and asked them to explain more fully their understandings of concepts included in these assessments. Student interviews revealed an inherent discrepancy between the teacher's tacit beliefs about students' current levels of understanding and their actual understanding. Since the majority of students completed in-class assignments accurately and quickly, the teacher assumed that students had a good understanding of the concepts being explored. Our interviews, however, revealed this an inaccurate assumption. For example, Sophia got all questions correct on her written assignment, yet she could not recall any spheres (lithosphere, hydrosphere, biosphere, or atmosphere) during her interview. Even after reviewing the assignment with her, she had difficulty explaining the spheres. In the interview she stated:

I: What about the bottom section of the sheet? Do you remember the spheres?
S: Yes. This is water [pointing to the hydrosphere]. This one is rock [pointing to the lithosphere]. No, the rock fits atmosphere better… I'm not sure
I: What sphere does the spider belong to?
S: I don't know. I'm not sure

Jonathan got most questions correct on the in-class assignment, but was not able to explain the two spheres he correctly identified on the assignment:

I: Look at the spheres on this sheet. What do you think the lithosphere would be?
J: Balloons, because lithosphere means air.
I: How about the hydrosphere?
J: [Rain] clouds, because of texture… I don't know.
I: What did you put for biosphere?
J: Spider, because of… I don't really know.
I: What about atmosphere?
J: Rock, because it is hard. I think. I don't know.

These initial data provided the teacher with evidence about the low efficacy of her assessment practices. Clearly, in-class, selected response assignments were not providing the teacher with an accurate understanding of students' conceptions. As a result, we discussed ways to realistically and accurately assess student knowledge construction by requiring students to explain their conceptions in writing as they did in the interviews. Owing to the teacher's ongoing concerns about her students' writing abilities, we decided to implement formative assessment prompts in constructed response format, but with a word bank of relevant terms and space for students to draw representations of science concepts. This format allowed students to use a combination of pictures and terms to illustrate their understandings. Two representative sections of this written document are shown in Fig. 2.

Unlike selected response assignments, an open-ended, constructed response format elucidated differing levels of student understanding. Subsequent student interviews substantiated the efficacy of this open-ended process by revealing students' evolving conceptual understanding. Additionally, the teacher was able to more precisely describe students' level of understanding after she analyzed their responses to open-ended prompts. Nonetheless, the teacher initially mistrusted this new strategy. For example, when looking at the document completed by Bradley, she wanted to disregard the fact that it contained several inaccurate ideas and was mostly blank. Based on his past academic performance and how quickly he completed the assignment, she clung to the belief that he understood the concepts. She noted:

> I think he gets it… My hesitation [with believing the process] is…I think he thinks, I don't know, school has been really easy for Bradley and he doesn't have to pay attention and he still gets it. Yet he cannot use words.

Our interviews of Bradley, however, repeatedly revealed that his understanding was limited. For example, when asked about soil formation he was only able to provide limited responses:

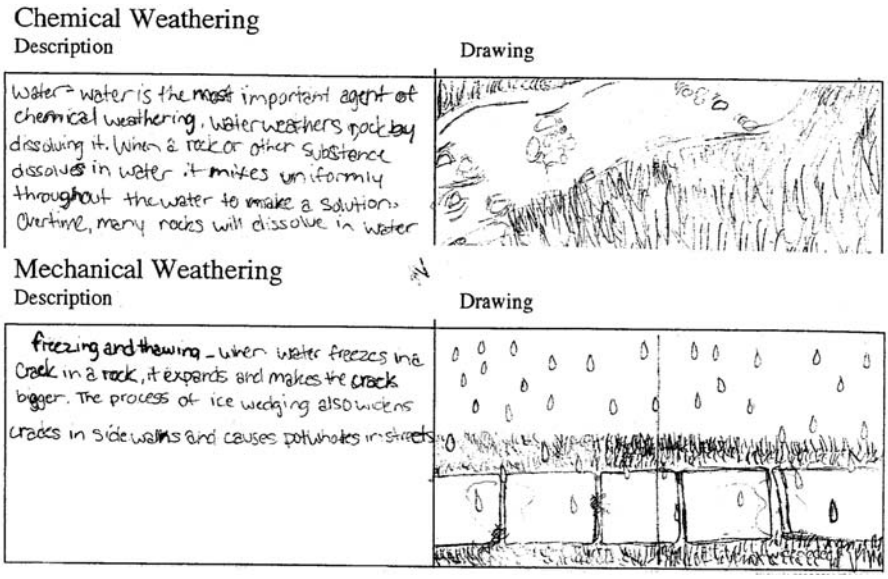

Fig. 2 A constructed-response formative assessment prompt that required students to use a combination of words and drawings

I: How does soil form?
B: When different things come together, like water, air…I forget the other ones.
I: When water and air come together? What happens when they come together?
B: They make soil.
I: How does that happen?
B: I don't know.

Faced with students' conceptions, the teacher began to acknowledge her selected-response assignments weren't accurately revealing students' understanding.

What type of student experiences resulted from the formative assessment process? How did their experience influence the formative assessment process? During initial stages of our inquiry process, data indicated that students were reluctant to demonstrate their understanding. Initially, students tried to copy factual information from friends or the science textbook. For instance, in Fig. 2 shown above, a student wrote parts of definitions given in the textbook even though she was able to describe terms in her own words during interviews. Although her pictures in the prompt and the interview demonstrated that she understood the relevant science concepts, she felt it necessary to use the textbook even though she was explicitly told not to use it.

Students' reluctance to express their current level of understanding initially proved to be problematic as we attempted to elucidate their conceptual development. The teacher expressed her frustration: "I wanted them not to copy straight from the book. I wanted them to do the writing! That's the picture from the book!" These students were merely following learned procedures for completing behaviorist-based assessments that had previously dominated classroom culture. As

students were reluctant to reveal their conceptual development, we discussed the need to make formative assessment more process-oriented rather than a product-oriented (i.e., documents produced from formative assessment). Thus, subsequent discussion centered on promoting student 'dialogue' as they constructed understanding. We formulated a plan that included (a) dialoguing with the students through continuous cycles of feedback, and (b) explicitly educating the students on formative assessment.

In order to effectively dialogue with students through continuous cycles of feedback and revision, the teacher realized she needed to provide more substantive comments than "you rock" or "good job." However, she was initially hesitant due to perceived time constraints and need to move forward with curricula. Nonetheless, she acknowledged the formative assessment process as a work in progress and committed to more cogent and descriptive feedback. Figure 3 demonstrates the iterative process of formative feedback cycle. Each time students wrote their conceptions, the teacher responded with questions to probe students' thinking. This process allowed students to elaborate and extend their thinking on a particular science concept.

We also sought to facilitate an explicit understanding of formative assessment among the students. This mainly occurred as classroom discussions between the teacher and students. In classroom observations, we documented that the teacher engaged students in several whole class and individual discussions about purposes and forms of formative assessment. During these discussions, she explained to them the necessity of revealing what they understood at that time, not simply attempting to ascertain the correct answer. She also clarified that formative assessment

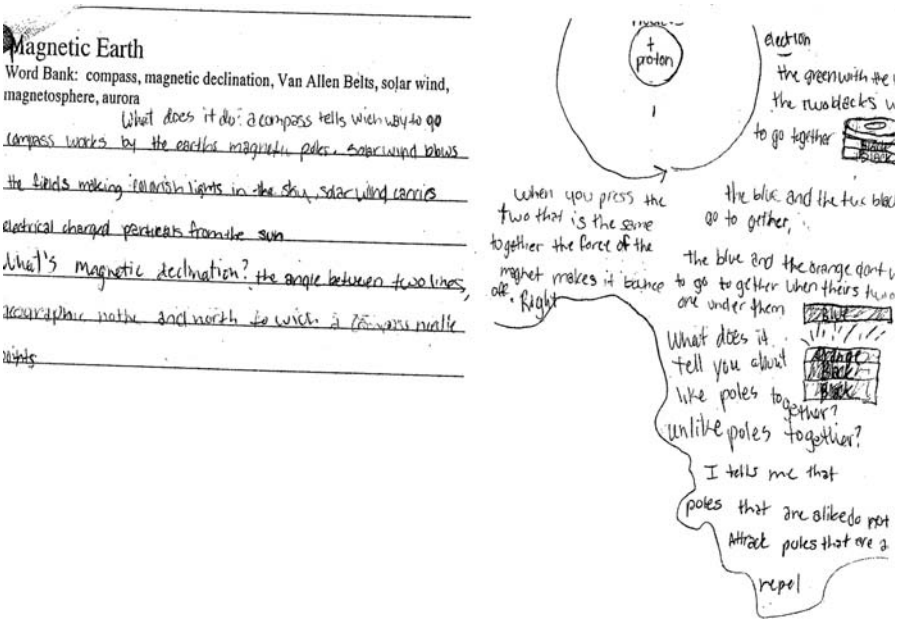

Fig. 3 A formative assessment prompt that demonstrated cycles of teacher feedback and student revision

strategies were not graded tests of students' achievement of knowledge. For example, during one lesson the teacher told students, "When I am asking you to do these drawings and writings, I'm not asking you to copy out of the book. I'm interested in…how you build it and incorporate it into your mind." She continued to discuss formative assessment: "It is not a test, it's not for grades. These help me to see what you know."

Both iterative cycles of feedback and explicit discussions of formative assessment allowed students to gain greater insight into the purposes of formative assessment. During the latter part of our study, the teacher commented on the authentic responses presented by students:

> It doesn't look like she's copying from the book. The pictures are so different…I think they are starting to trust me more. We've had conversations about how this is important to help show me how they are building with their own words and understandings.

Data revealed that most students responded to the revised formative assessment process once they understood and trusted the purpose. However, not all of their reactions were positive. A couple of students became increasingly reluctant to demonstrate their understanding. This was revealed in the experiences of two high-achieving students who attempted to renegotiate for a return to behaviorist-based assessments. When the research began, all students were excited to be interviewed, including Sophia and Bradley. However, when Bradley, a student who traditionally received high marks on standardized tests, could not answer interviewer's questions about conceptual understandings, he became increasingly irritated and elected to no longer participate in interviews. The interviewer noted:

> He…shut down on me. I remember the beginning, the very first interview I did with him, he was all ready to tell me what he knew. Then along the way he found out that I was asking deeper questions…now he knows I'm going to ask questions that he doesn't know and he doesn't want to try anymore.

Likewise, when interviews with Sophia revealed she could not explain concepts despite the fact that she received high marks on initial worksheets, she also decided not participate in later interviews. The teacher continued to work on establishing a trusting environment for them during this period by encouraging them to dialogue with her and stressing inherent differences between formative and summative assessments.

The teacher noted the increase in student involvement in the formative assessment process by the completion of the study. In contrast to high-achieving students, other students who had traditionally performed poorly welcomed the formative process, and began to flourish academically. For example, one student with learning disabilities became more attentive to his learning. The teacher noted, "he's the most responsive that I've seen" and of another student with diagnosed learning difficulties, she noted was "very good about doing this [process]."

What practical implications emerged as a result of integrating formative assessment into the teacher's daily instructional practices? Reflections by the inquiry group provided insights into practical implications this process had on the

teachers' daily instructional practice. Three practical implications have been noted in the previous section on students' experiences. These included the need for the teacher to (1) dialogue with students through continuous cycles of feedback and revision, (2) explicitly educate students about the formative assessment process, and (3) establish a trusting environment where students could explore their conceptual development without fear of penalty. A fourth implication is elaborated below.

As the teacher became more efficient at eliciting student conceptions through formative assessment, she expressed anxiety regarding the amount of time required to provide students with meaningful feedback. She increasingly made comments such as "…it takes away time from other topics," "it's labor intensive, I can't do it all the time," and "there's a time crunch. We need to start soil." These comments revealed her desire to keep pace in covering curricula, regardless of student misconceptions revealed in formative assessments. While other members of the cooperative inquiry group understood the importance of addressing student misconceptions by providing additional feedback and time to master learning goals, she responded

> I'll give them more time …but it's tricky because… I felt like I spent a lot of time already."

In another discussion, the teacher stated,

> I think it's [formative assessment] a nice tool, but time-wise I feel like I am constantly going 'come on, come on.' So it's no wonder they feel that way when really we need to slow down. It's not a race. I mean, if we had more time to slow down and think about what we need…I agree [with slowing down], but I'm not feeling like I can just get there.

Meeting the needs of students had differential meanings among members of the cooperative inquiry team. To teacher educators, addressing students' needs through formative assessment meant covering objectives more fully until all students understood the concepts. We were distressed that we were still uncovering misconceptions about landforms even though class instruction had moved to the next curriculum topic, water erosion. We sought a formative assessment process envisioned by Shepard (2005), which "uses insights about a learner's current understanding to alter the course of instruction and thus support the development of greater competence" (p. 67). Yet we felt unable to fully enact that process. To the teacher, addressing students' needs through formative assessment was not so straightforward. In her mind, there was conflict between making instructional adjustments in response to students' learning needs, and covering all aspects of the curriculum necessary for successful performance on summative assessments. She expressed this conflict with statements such as

> I need to teach them how to take those [standardized] tests. It just needs to be another piece they need to learn…people are going to look at their scores and say they don't know that…I wish we could go a little bit long with this because I think they really do know a lot, it just takes longer to learn something…I'm worried the misconceptions are going to mushroom.

Regardless of challenges she perceived, the teacher's praxis continued to evolve. During an interview, a student addressed her own misconceptions about landforms during a discussion on water erosion:

> I: What are some other causes for erosion?
> T: Wind, gravity, glaciers, floodplains…no, something with rain.
> I: What about deposition?
> T: [It's] when sediment gets moved around and forms new lands. Like a river could break up [land] and make little islands. New landforms are made.

Hearing this student's dialogue aided the teacher in realizing unifying concepts throughout the curricula. She came back to the group with an idea:

> I wonder if I could start with these big ideas…and then every week come back to these and say, 'what can you add to erosion, what did you learn about…?' Something to show that they added to their understanding of the concept.

She began to look at her instructional units and explore the interconnections that provided potential opportunities to address misconceptions while simultaneously advancing with curricula.

Ultimately, the teacher's evolving conceptions of formative assessment and challenges that she encountered in enacting the formative assessment process forced us, as teacher educators, to view our own conceptions through a critical lens. The teacher's reflections helped us realize that individual concepts covered in curricula need not be fully understood by students before moving on to subsequent lessons. The experiences of the teacher and students indicated that some might not achieve complete conceptual understanding until they encountered unifying ideas across topics.

From this insight, unifying concepts or big ideas became the focus of our cooperative inquiry. The teacher reviewed a subsequent unit on electricity and magnetism and proposed, "we should start with these big ideas and work backwards and just see if it works…I'm going to just take soil, deposition, weathering, and erosion…and have a big sheet…and then every week, we can add to it." In this manner, students learned big ideas while also reflecting on their own understandings of individual concepts. A small section of the formative assessment that corresponds to big ideas for this unit is shown in Fig. 3. Students received this sheet at the beginning of the unit; they provided their initial understanding of the big ideas and the teacher provided guiding questions in response.

As instruction progressed, students received the formative assessment sheet again. Using the teacher's guiding questions they were instructed to add to their initial explanations of the big ideas. In Fig. 4, a student wrote a small amount about the first concept when she initially responded. The second time, she added information about 'magnetic north,' and the 'nature of magnetism,' by elaborating her description and drawing. In the end, this student submitted a sheet filled with developing ideas of concepts outlined in the unit. This iterative formative assessment process continued for the duration of the instructional unit. Development and implementation of a strategy that started from overarching concepts allowed all members of the cooperative inquiry team to realize a formative assessment process

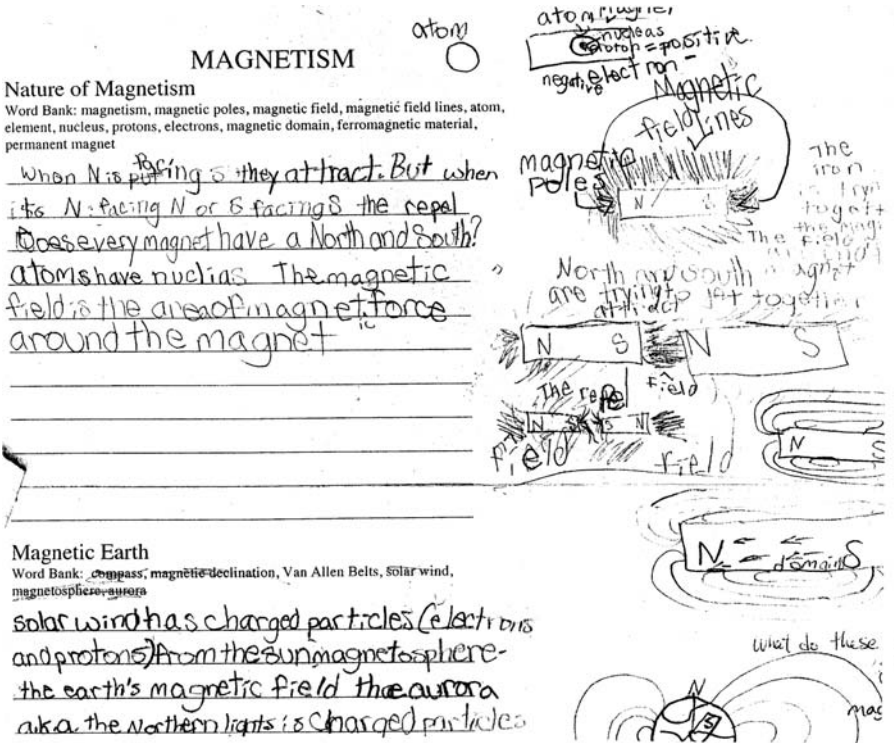

Fig. 4 An interactive formative assessment probe showing one student's conceptual development over the course of an instructional unit

that was practical in light of classroom realities, while still focusing on students' conceptual development.

Summary and Conclusion

Our findings revealed practical problems in behaviorist-based formative assessments. After the teacher confronted limitations of these strategies, an open-ended formative assessment process emerged. Initially, our revised formative assessment process was influenced by student resistance to sharing their understandings. The teacher addressed this resistance by dialoguing with students, which established a more trusting relationship and allowed students to communicate more fully their developing conceptions, regardless of accuracy. In addition, she explicitly addressed purposes and processes of formative assessment with her students. Over time, most students understood the formative assessment process; most were no longer reluctant to participate. Once we realized a more sound and viable formative assessment process, we became increasingly focused on creating a more reflexive process. While the teacher expressed reluctance in adjusting the pace of instruction, she did develop deeper understanding regarding the impact of formative assessment on instructional planning. Our understanding of practical challenges and benefits to

implementing high quality formative assessment in a science classroom could not have been achieved without prolonged engagement in the classroom and ongoing dialogue among members of the cooperative inquiry group.

Discussion and Implications

Teachers' assessment decision-making is a process in which demands for external accountability are balanced with their own values and conceptions of classroom assessment (McMillan 2003). Collaborating with a middle level science teacher has afforded us many new insights with regard to preparing science teachers to fully realize formative assessment in classrooms. These insights include the need to address (a) assessment practices grounded in tacit understandings of student conceptual development, (b) pressures to maintain a pace necessary for covering content standards, and (c) students' resistance to formative assessment due to naïve notions of assessment and/or mistrust of assessment processes.

Data collected during this study provided insights into the teacher's emergent understanding of the formative assessment process. The formative assessments we developed through cooperative inquiry were antipodal to the teacher's established, yet tacit approach to formative assessment; an approach that did not accurately reveal the students' conceptual development. Bell and Cowie (2001) noted that teachers often tacitly undertake formative assessment and are unable to explicitly describe students' conceptions. Lack of awareness was evident here in our teacher's explanations of using 'gut feelings.' We identified and actively explored tacit processes that the teacher utilized to follow student learning progressions. By doing so, we were able to make these tacit processes more explicit. The teacher's confrontation with the discrepancy between her tacit understandings and students' actual conceptions catalyzed our efforts to incorporate a reflexive and explicit formative assessment process into practice. These findings are similar to Bell and Cowie (2001), who found that teachers' experiences with research made more visible the forms and processes of formative assessment used in their classrooms.

With regard to teacher preparation, the findings herein support the necessity of making teachers' tacit processes and 'gut instincts' more explicit in order to explore how and to what extent formative processes can be incorporated into classroom practices. Making tacit processes explicit has implications for research and practice on inservice teacher professional development. We suggest that self-reflection and exploration of teacher's formative assessment practices should not occur only at the end of professional development programs. Rather, we suggest teacher educators provide teachers with opportunities to contemplate the efficacy of classroom assessment practices throughout the duration of inservice professional development programs, including prior to participation. We suggest the use of case studies, in which teachers compare other practitioners' conceptions of students, sample classroom documents, and student interviews, in order to contemplate the efficacy of differing formative assessment practices.

Teachers often favor assessment processes presented in professional development programs, especially those purported to improve teaching and learning, while

rejecting assessment solely for student accountability purposes (Brown 2004). At the same time, teachers are pressured to keep rapid pace necessary to comprehensively cover curriculum topics prior to summative and accountability assessments. Thus, teachers' learning about assessment should be embedded in larger professional development efforts. As teachers' time is already overburdened, professional development related to formative assessment is unlikely to be effective unless it is directly tied to students' content learning and achievement on accountability tests (Shepard 2003). This was so in our case, as the teacher came to value the formative assessment process over a process that focused solely on standardized tests and student accountability. However, our formative process one in which the teacher could accurately assess student conceptions while also supporting her efforts to help students survive in an era of educational accountability.

Delpit (1995) cautioned against dismissing such an issue of power; in this case, the issue is external accountability through standardized test scores. The teacher was responsible for the learning of a diverse group of students, mostly from lower-socioeconomic situations, and although the formative assessment process was highly valued by the teacher, we also realized it was not in the best interest of these children to take steps that would negatively impact their achievement on accountability assessments. We suggest that professional development on formative assessment should not only prepare teachers to implement formative assessment in classrooms, but also support their efforts to prepare students for high stakes testing (Black 2003). By doing so, formative assessment becomes a relevant and necessary component of classroom instruction.

The cooperative nature of our inquiry group fostered a more reliable and coherent approach to formative assessment, one that was distal to the traditional approach previously used. However, fostering student involvement in the formative assessment forced us to confront students' naïve notions and mistrust of the formative assessment process. As formative assessment requires an alternative view of relationships between teacher and student, teachers must cultivate a trusting and reciprocal relationship with students (Bell 2007). Establishing effective student-teacher relationships requires more than teachers simply responding to students' conceptions; it requires a shift in classroom roles. Essentially, authority must be shared among teacher and students, thereby building a more egalitarian classroom environment (Maher and Tetreault 1993; Middlecamp and Subramaniam 1999). The teacher becomes a facilitator and students are empowered to redefine their role in classroom assessment (Black and Harrison 2001). In light of our experiences, we suggest that professional development on formative assessment should prepare teachers to foster such a shift in roles not only for themselves, but for the students as well.

We found students in this classroom experienced formative assessment in divergent ways. High-achieving students viewed formative assessment practices negatively, while low-achieving students seemed to benefit most in terms of achievement. Although our findings suggest potentially negative impacts of the formative assessment process on high-achieving students, these findings are tentative. Aggregating data on students' experiences must be carefully pursued, owing to students' differing experiences within the same classroom (Nuthall 2004).

The nature of this study limits generalizations about students' achievement or experiences with formative assessment; however, differential effects of formative assessment have been suggested by others (e.g., Black 1998), thus warranting further investigation. Moreover, future investigations should be conducted cautiously so that students who are potentially threatened by the process of eliciting and confronting their own misconceptions are not asked to do so by those with whom they are unfamiliar (i.e., post-secondary researchers) or have not yet established a trusting and reciprocal relationship.

In terms of supporting inservice teachers in the enactment and refinement of formative assessment, our research demonstrates that teachers must be skilled in preparing students to understand and take part in a formative assessment process outlined in assessment reform documents (AAAS 1998; NRC 1999, 2007) and envisioned by science education researchers (Black and Wiliam 1998; Shepard 2000, 2005). One possible strategy is to promote the use of written dialogue, an assessment process that does not readily resemble traditional quizzes or tests, as a vehicle for encouraging student 'talk' with the teacher. Student-teacher dialogues provide opportunities for teachers to respond and reorient students' thinking (Black and Wiliam 1998). However, we contend that it's not a matter of simply offering a dialogue in which student can engage. Teacher preparation must also include ways to address the inherent complexities associated with student mistrust and resistance. We suggest future research should explore pedagogies that support formative assessment by establishing effective student-teacher relationships. Additionally, establishing long-term teacher collaborations may prove viable negotiating the relational complexities of enacting formative assessment.

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